LWDA FITS-IDI File Format

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1 Introduction

FITS (Flexible Image Transport System) files are binary files used to archive and transport astronomical data sets. FITS-IDI (Interferometry Data Interchage) files are FITS files which have been specialized to hold raw radio instrument interferometry data. The LWDA instrument may record and archive raw UV visibility data in FITS-IDI files.

1.1 FITS-IDI File Structure

Like all FITS files, a FITS-IDI file is composed of a sequence of one or more Header Data Units (HDU's). An HDU consists of a header followed by a data section. The header format for all FITS HDU's is identical, and consists of one or more keyword values. These keywords associate an 8-character name with a value and optional comment. The format of the HDU data section is dependent on the type of HDU, and will be indicated by keyword values in the associated header. The first HDU in a FITS file is the primary HDU. It must be either an Image HDU or Random Groups HDU. In FITS-IDI files, the primary HDU is a Random Groups HDU, but this primary HDU does not contain a data section. Instead, the FITS-IDI file data is contained in a series of Binary Table Extension HDU's which follow the primary HDU.

LWDA FITS-IDI files contain a subset of the defined IDI binary extension tables. LWDA FITS-IDI files are required to have the following HDU's.

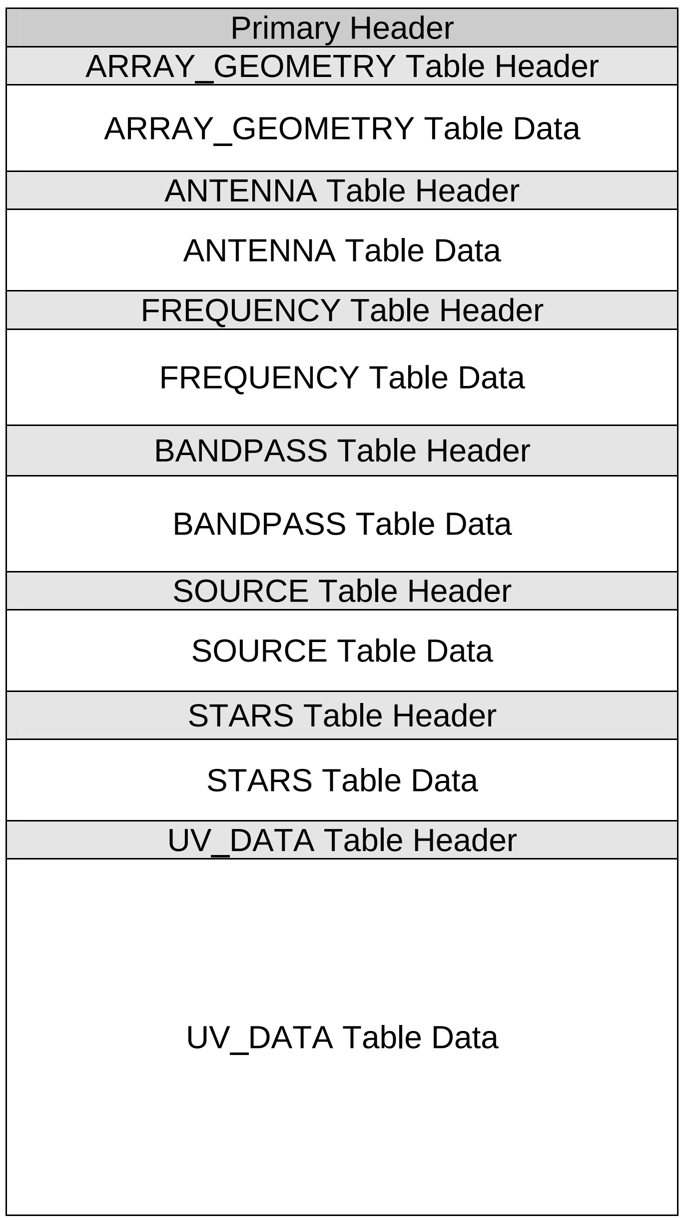
Table 1 - Required Header Data Units

HDU	Description
PRIMARY	LWDA IDI file meta-data
ARRAY_GEOMETRY	Describes LWDA station antenna layout.
ANTENNA	Describes LWDA antenna characteristics.
FREQUENCY	Describes LWDA instrument frequency configuration.
BANDPASS	Describes antenna frequency response and relative gain.
SOURCE	Describes LWDA UV data observation ephemerdes.

STARS	Describes LWDA UV ancillary data observation ephemerdes.
UV_DATA	Contains observation LWDA UV visibility data and associated parameters.

The diagram below shows the general layout of an LWDA FITS-IDI file

Figure 1 - General Structure of LWDA FITS-IDI Files



The layout shown above is describes the minimum contents of a valid LWDA FITS-IDI file. Additional HDU's may be added for such purposes of calibration and annotation.
LWDA FITS-IDI files make assumptions which reduces their complexity with respect to the full IDI standard. LWDA IDI files are only required to contain the HDU's listed above, even though the IDI standard defines many additional types of calibration tables. More importantly, LWDA IDI files only contain one frequency band (IF) and one polarization band (Stokes). This results in a simplified structure in many respects:

- The FREQUENCY table contains only one row, describing the single IF band
- The UV data matrix BAND (IF) axis only contains one pixel
- The NO_BAND global keyword is always set to '1'
- The UV data matrix STOKES (polarization) axis only contains one pixel
- The NO_STKD global keyword is always set to '1'.

This only leaves the length of the UV data matrix FREQ axis variable.

1.2 Reference Documents

Definition of the Flexible Image Transport System (FITS), FITS Standard Version 2.1b, IAU FITS Working Group, December 2005.

AIPS Memo No. 102: The FITS Interferometry Data Interchange Format, Chris Flatters, NRAO, August 2000.

For the official FITS-IDI specification and other documentation, see http://www.aoc.nrao.edu/aips/FITS-IDI.html.

1.3 Required IDI Keywords

All of the binary table extension HDU headers in a FITS IDI file are required to include a set of global, mandatory keywords. These global keywords are listed below.

Table 2 - Required Binary Table Keywords

Keyword	Type	Description	Value
XTENSION	A	FITS extension HDU type.	‘BINTABLE’
BITPIX	I	FITS binary table data type.	8
NAXIS	I	Number of binary table dimensions.	2
PCOUNT	I	Number of bytes of associated data in the HDU	0
GCOUNT	I	Number of binary tables in the HDU	1
EXTVER	I	IDI binary table instance number	1
NO_STKD	I	Number of UV data polarization bands	1
STK_1	I	First polarization band ID	Input data parameter -1 = RR -2 = LL -3 = RL -4 = LL
NO_CHAN	I	Number of UV data frequency channels	>= 1 (input data parameter)
NO_BAND	I	Number of UV data frequency bands (IF)	1
REF_FREQ	E	Frequency of first (lowest) channel of the UV data in Hz.	Input data parameter.
CHAN_BW	E	Frequency bandwidth of the channels of the UV data in Hz.	Input data parameter.
REF_PIXL	E	Frequency reference channel (pixel) number	1.0
ARRNAM	A	Array name.	‘LWDA’
OBSCODE	A	Observation name.	‘ZAyymmdd’ where yy-mm-dd is the date of the first UV data set in the file

RDATE	D	File reference date.	'yyyy-mm-dd' giving the UTC date of the first UV data set in the file
END	-	FITS required keyword to mark end of header	

The REF_FREQ, CHAN_BW, and NO_CHAN provide the frequency channel characterization for LWDA IDI files. The frequency of channel 'N' is given by:

F = ((N – REF_PIXL) * CHAN_BW) + REF_FREQ

The total bandwidth of the single frequency band is given by:

B = NO_CHAN * CHAN_BW

LWDA IDI files always characterize the channels in the frequency band as 'upper sideband', so that the reference pixel is always '1' and designates the lowest frequency channel.

2 Primary HDU

A FITS-IDI is required to have a Random Groups HDU as the first member of the file. The primary header is the first data structure in a FITS-IDI file. In an IDI file, the primary HDU does not contain any data, but the header keywords provide useful meta-information about the file. File format identifiers, version identifiers, history logs, and comment logs may be contained in the primary header keywords.

2.1 Primary Header

An LWDA FITS-IDI primary header is required to have the following keywords.

Table 3 - Primary Header Required Keywords

Keyword	Type	Description	Value
SIMPLE	L	Flag to indicate standard FITS format	T
BITPIX	I	Primary data array type	8
NAXIS	I	Number of axes in primary data array	0

EXTEND	L	Flag to indicate FITS extension HDU's are present	T
GROUPS	L	Flag to indicate FITS Random Groups data array	T
GCOUNT	I	Number of groups in primary data array	0
PCOUNT	I	Number of group parameters in primary data array	0
OBJECT	A	FITS standard states this is the name of the object observed.	'BINARYTB'
TELESCOP	A	Name of the telescope used to collect the UV data.	'LWDA'
OBSERVER	A	Name of the person collecting the UV data	'ZASKY'
ORIGIN	A	Name of the institution collecting the UV data	Input data parameter.
DATE-OBS	D	UTC day LWDA UV raw data was collected	Input data parameter.
DATE-MAP	D	UTC day LWDA UV data was archived in FITS-IDI file	Input data parameter.
LWDATYPE	A	LWDA FITS file type.	'IDI-ZA'
LWDAMAJV	I	LWDA FITS-IDI file format major version number.	2
LWDAMINV	I	LWDA FITS-IDI file format minor version number.	0

The IDI file header may contain HISTORY and COMMENT keywords with multiple CONTINUE keywords following. The LWDATYPE, LWDAMAJV, and LWDAMINV keywords are specific to LWDA and are not included in the base FITS-IDI specification.

3 ARRAY_GEOMETRY Table HDU

The ARRAY_GEOMETRY HDU is a binary table extension HDU. The ARRAY_GEOMETRY table contains information about the physical layout of the LWDA array. The ECI position of the array center as well as the ECI vectors of the 16 antennas relative to the array center are recorded in this table. LWDA FITS-IDI files contain a single ARRAY_GEOMETRY table describing the 16-element LWDA station. The array layout information is taken from official surveys of the LWDA site.

3.1 ARRAY_GEOMETRY Table Header

In addition to the required LWDA IDI header keywords, the ARRAY_GEOMETRY table header contains the following keywords.

Table 4 - ARRAY_GEOMETRY Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	'ARRAY_GEOMETRY'
NAXIS1	I	Number of bytes in each row of ARRAY_GEOMETRY table	72
NAXIS2	I	Number of rows in ARRAY_GEOMETRY table	16
TFIELDS	I	Number of columns in ARRAY_GEOMETRY table	7
TABREV	I	ARRAY_GEOMETRY table format version	1
FRAME	A	Array vector reference frame	'GEOCENTRIC'
ARRAYX	E	Array center ECI X coordinate	LWDA center ECI X meters
ARRAYY	E	Array center ECI Y coordinate	LWDA center ECI Y meters
ARRAYZ	E	Array center ECI Z coordinate	LWDA center ECI Z meters
NUMORB	I	Number of orbital parameters	0
FREQ	E	Array reference frequency	Set to REF_FREQ global keyword value
TIMSYS	A	Array reference time system	'UTC'
GSTIA0	E	Greenwich apparent sidereal time at 0 hours	GAST in degrees at 00:00:00 on RDATE
DEGPDY	E	Earth's rotation rate in degrees per day	Difference in sidereal times for one UTC day on RDATE
UT1UTC	E	Difference UT1 – UTC	0.0
IATUTC	E	Difference TAI – UTC	Leap seconds for RDATE
POLARX	E	North pole X offset	0.0
POLARY	E	North pole Y offset	0.0

3.2 ARRAY_GEOMETRY Table Data

LWDA FITS-IDI file ARRAY_GEOMETRY tables contain 16 rows and 7 columns. Each row describes one antenna in the LWDA array. The column data is described below.

Table 5 - ARRAY_GEOMETRY Table Columns

Column	Name	Format	Units	Description	Value
1	ANNAME	8A		Antenna name	'LWDA'nnn
2	STABXYZ	3D	METERS	Antenna relative position vector ECI components	Antenna X,Y,Z components relative to array center
3	DERXYZ	3E	METERS /SEC	Antenna velocity vector components	0.0
4	ORBPARM	1D		Orbital parameters	0.0
5	NOSTA	1J		Antenna ID number for station	1 – 16 (matches ID from survey)
6	MNTSTA	1J		Antenna mount type.	0 (alt-azimuth)
7	STAXOF	3E	METERS	Antenna axis offset	0.0

4 Antenna Table HDU

The ANTENNA HDU is a binary table extension HDU. The ANTENNA table describes the antenna polarization characteristics. LWDA FITS-IDI file contain one ANTENNA table describing the 16-element LWDA station.

4.1 ANTENNA Table Header

In addition to the required LWDA IDI header keywords, the ANTENNA table header contains the following keywords.

Table 6 - ANTENNA Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	'ANTENNA'
NAXIS1	I	Number of bytes in each row	54

		of ANTENNA table	
NAXIS2	I	Number of rows in ANTENNA table	16
TFIELDS	I	Number of columns in ANTENNA table	13
TABREV	I	ANTENNA table format version	1
NOPCAL	I	Number of polarization calibration constants.	0
POLTYPE	A	Antenna polarization type	'APPROX' (circular approximation)

4.2 *Antenna Table Data*

LWDA FITS-IDI file ANTENNA tables contain 16 rows and 13 columns. Each row describes one antenna in the LWDA array. The column data is described below.

Table 7 - ANTENNA Table Columns

Column	Name	Format	Units	Description	Value
1	TIME	1D	DAYS	Difference of antenna table time interval center time and RDATE 0 hours	0.0
2	TIME_INTERVAL	1E	DAYS	Antenna table time interval width	2.0
3	ANNAME	8A		Antenna name	'LWDA'nnn Matches value in ARRAY_GEOMETRY ANNAME column
4	ANTENNA_NO	1J		Antenna ID number for station	1 – 16 Matches value in ARRAY_GEOMETRY NOSTA column
5	ARRAY	1J		Array ID number.	1
6	FREQID	1J		Frequency setup ID number	1

7	NO_LEVELS	1J		Number of digitizer levels	1
8	POLYTYA	1A		Feed A polarization direction.	‘R’
9	POLAA	1E	DEGREES	Feed A polarization.	0.0
10	POLCALA	1E		Feed A polarization parameters.	0.0
11	POLYTYB	1A		Feed B polarization direction.	‘L’
12	POLAB	1E	DEGREES	Feed B polarization.	0.0
13	POLCALB	1E		Feed B polarization parameters.	0.0

5 Frequency Table HDU

The FREQUENCY HDU is a binary table extension HDU. The FREQUENCY table describes the LWDA array frequency setup. LWDA FITS-IDI file contain one FREQUENCY table describing the 16-element LWDA station.

5.1 FREQUENCY Table Header

In addition to the required LWDA IDI header keywords, the ANTENNA table header contains the following keywords.

Table 8 - FREQUENCY Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	‘FREQUENCY’
NAXIS1	I	Number of bytes in each row of FREQUENCY table	28
NAXIS2	I	Number of rows in FREQUENCY table	1
TFIELDS	I	Number of columns in ANTENNA table	6

TABREV	I	FREQUENCY table format version	2

5.2 *Frequency Table Data*

LWDA FITS-IDI file FREQUENCY tables contain 1 row and 6 columns. The one row describes the single frequency band setup of the LWDA array during the observations. The column data is described below.

Table 9 - FREQUENCY Table Columns

Column	Name	Format	Units	Description	Value
1	FREQID	1J		Frequency setup ID number	1
2	BANDFREQ	1D	HZ	Frequency band base offset.	0.0
3	CH_WIDTH	1E	HZ	Frequency channel width.	Input data parameter. (Equal to CHAN_BW keyword value)
4	TOTAL_BANDWIDTH	1E	HZ	Frequency band width	Product of NO_CHAN and CHAN_BW keyword values.
5	SIDEBAND	1J		Sideband flag	1 (indicates upper sideband definition).
6	BB_CHAN	1J		?	0.0

6 BANDBASS Table HDU

The BANDPASS table contains the tabulated frequency response of the antenna electronics. Each frequency channel in the UV data set is assigned a complex value giving both for the magnitude and the phase of the bandpass response. Each row in the BANDPASS table describes the bandpass response of one antenna in the array, so each antenna and receiver may be calibrated separately.

6.1 *BANDPASS Table Header*

In addition to the required LWDA IDI header keywords, the BANDPASS table header contains the following keywords.

Table 10 - BANDPASS Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	'BANDPASS'
NAXIS1	I	Number of bytes in each row of BANDPASS table	44 + (8 * N) where N is the number of frequency channels
NAXIS2	I	Number of rows in BANDPASS table	16
TFIELDS	I	Number of columns in BANDPASS table	11
TABREV	I	BANDPASS table format version	1
NO_ANT	I	Number of antennas described in BANDPASS table.	16
NO_POL	I	Number of polarizations described in BANDPASS table.	1
NO_BACH	I	Number of frequency channels tabulated in BANDPASS table	>= 1 (input data parameter; equal to global keyword NO_CHAN value)

6.2 BANDPASS Table Data

LWDA FITS-IDI file BANDPASS tables contain 11 columns and 16 rows. Each row in the BANDPASS table corresponds to one antenna in the LWDA array. The column data is described below. Each set of bandpass response values is contained in the BREAL_1 and BIMAG_1 columns in the table. These arrays are NO_BACH (=NO_CHAN) in length.

Table 11 - BANDPASS Table Columns

Column	Name	Format	Units	Description	Value
1	TIME	1D	DAYS	Difference of bandpass table time interval center time and RDATE 0 hours	0.0
2	TIME_INTERVAL	1E	DAYS	Bandpass table time interval width	2.0

3	SOURCE_ID	1J		Source ID number	1
4	ANTENNA_NO	1J		Antenna ID number for station	1 – 16 (matches value in ANTENNA ANTENNA_NO column)
5	ARRAY	1J		Array ID number	1
6	FREQID	1J		Frequency setup ID number	1
7	BANDWIDTH	1E	HZ	Frequency band width described by bandpass	Product of NO_CHAN and CHAN_BW keyword values.
8	BAND_FREQ	1D	HZ	Frequency band base offset.	0.0
9	REFANT_1	1J		Reference antenna ID number	1
10	BREAL_1	nE		Bandpass response real component	Input calibration data
11	BIMAG_1	nE		Banpass response imaginary component	Input calibration data

7 SOURCE Table HDU

The SOURCE HDU is a binary table extension HDU. The SOURCE table describes the LWDA array pointing setup at the time of observations. LWDA FITS-IDI file contain one SOURCE table describing the pointing locations for all of the UV data sets contained in the UV_DATA table.

7.1 SOURCE Table Header

In addition to the required LWDA IDI header keywords, the SOURCE table header contains the following keywords.

Table 12 - SOURCE Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	'SOURCE'
NAXIS1	I	Number of bytes in each row of SOURCE table	152
NAXIS2	I	Number of rows in SOURCE table	Input data parameter
TFIELDS	I	Number of columns in SOURCE	23

		table	
TABREV	I	SOURCE table format version	1

7.2 SOURCE Table Data

LWDA FITS-IDI file SOURCE tables contain 23 columns and a variable number of rows. Each row in the SOURCE table corresponds to one UV data set time, and therefore, one instrument pointing direction. For all-sky image IDI files, the instrument is assumed zenith pointing, and a row in the SOURCE table is added describing the celestial coordinates of the zenith position at the time of the observation. The column data is described below.

Table 13 - SOURCE Table Columns

Column	Name	Format	Units	Description	Value
1	ID_NO.	1J		Source ID number	1 - n
2	SOURCE	16A		Source name	'ZA'hhmmsst where hh:mm:ss is the LWDA array local sidereal time for observation
3	QUAL	1J		Source qualifier number.	0
4	CALCODE	4A		Source calibrator code.	' '
5	FREQID	1J		Source frequency ID	1
6	IFLUX	1E	JY	Source I flux density	0.0
7	QFLUX	1E	JY	Source Q flux density	0.0
8	UFLUX	1E	JY	Source U flux density	0.0
9	VFLUX	1E	JY	SourceV flux density	0.0
10	ALPHA	1E		Source spectral index	0.0
11	FREQOFF	1E	HZ	Source frequency offset	0.0
12	RAEPO	1D	DEGREES	Source J2000 equatorial position RA coordinate	Zenith position equatorial coordinates precessed to J2000
13	DECPO	1D	DEGREES	Source J2000 equatorial position DEC coordinate	Zenith position equatorial coordinates precessed to J2000
14	EPOCH	1D		Coordinate epoch	2000.0

15	RAAPP	1D	DEGREES	Source apparent equatorial position RA coordinate	Ephemeris for zenith position at observation time.
16	DECAPP	1D	DEGREES	Source apparent equatorial position DEC coordinate	Ephemeris for zenith position at observation time.
17	SYSVEL	1D	METERS / SEC	Systematic velocity.	0.0
18	VELTYP	8A		Systematic velocity reference frame.	‘GEOCENTR’
19	VELDEF	8A		Systematic velocity convention.	‘OPTICAL’
20	RESTFREQ	1D	HZ	Line rest frequency.	Value of REF_FREQ keyword.
21	PMRA	1D	DEGREES / DAY	Source proper motion RA coordinate	0.0
22	PMDEC	1D	DEGREES / DAY	Source proper motion DEC coordinate	0.0
23	PARALLAX	1E	ARCSEC	Source parallax.	0.0

The local sidereal time of the observation is recorded in the SOURCE column of the SOURCE table for each UV data set in the IDI file. This is equivalent to the RA coordinate of the zenith position at the time of the observation, given in hours, minutes, seconds, and tenths of a second.

8 STARS Table HDU

The STARS HDU is a binary table extension HDU. The STARS table describes ancillary ephemeris information at the time of observations. LWDA FITS-IDI file contain one STARS table. This information is used by LWDA-specific data analysis software. The STARTS HDU not included in the base FITS-IDI specification.

8.1 STARS Table Header

In addition to the required LWDA IDI header keywords, the STARS table header contains the following keywords.

Table 14 - SOURCE Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	‘STARS’
NAXIS1	I	Number of bytes in each row of SOURCE table	20
NAXIS2	I	Number of rows in SOURCE table	Input data parameter
TFIELDS	I	Number of columns in SOURCE table	3
TABREV	I	STARS table format version	1

8.2 STARS Table Data

LWDA FITS-IDI file STARS tables contain 3 columns and a variable number of rows. Each row in the STARS table corresponds to one UV data set time, and therefore, one instrument pointing direction. Each row is marked with an ID value for reference in the SOURCE table. The column data is described below.

Table 15 - STARS Table Columns

Column	Name	Format	Units	Description	Value
1	SOURCE	1J		Source ID number	1 - n
2	SUNGALL	1D	DEGREES	Sun’s current apparent galactic longitude	Solar galactic longitude (L) in degrees
3	SUNGALB	1D	DEGREES	Sun’s current apparent galactic latitude	Solar galactic latitude (B) in degrees

9 UV_DATA Table HDU

The UV_DATA table contains the actual LWDA array correlation visibility data. The data are stored as a multi-dimensional matrix of form [time, baseline, frequency, complex]. Each complete visibility data set is marked with a new observation time. This data set will also refer to one row in the SOURCE table describing the pointing direction of the array at that time. Each visibility data set contains up to 136 baseline pairs from the 16 antennas of the LWDA array. The data sets may contain multiple frequency channels. See Appendix A - UV Data Matrix for a description of the UV data matrix. Keyword values in the UV_DATA table header provide the dimension sizes of the data matrix.

9.1 UV_DATA Table Header

In addition to the required LWDA IDI header keywords, the UV_DATA table header contains the following keywords.

Table 16 - UV_DATA Header Required Keywords

Keyword	Type	Description	Value
EXTNAME	A	FITS extension name	'UV_DATA'
NAXIS1	I	Number of bytes in each row of UV_DATA table	52 + (12 * N) where N is the number of frequency channels
NAXIS2	I	Number of rows in UV_DATA table	Input data parameter.
TFIELDS	I	Number of columns in UV_DATA table	13
TABREV	I	UV_DATA table format version	1
NMATRIX	I	Number of UV data matrices in table.	1
MAXIS	I	Number of UV data matrix axes.	6
MAXIS1	I	Number of COMPLEX axis pixels	2
CTYPE1	A	Name of COMPLEX axis.	'COMPLEX'
CDELT1	E	COMPLEX axis delta value.	1.0
CRPIX1	E	COMPLEX axis reference pixel.	1.0
CRVAL1	E	COMPLEX axis reference value.	1.0
MAXIS2	I	Number of STOKES axis pixels	1 (equal to global keyword NO_STKD value)
CTYPE2	A	Name of STOKES axis.	'STOKES'
CDELT2	E	STOKES axis delta value.	-1.0
CRPIX2	E	STOKES axis reference pixel.	1.0
CRVAL2	E	STOKES axis reference value.	Input data parameter (equal to global keyword STK_1 value).

MAXIS3	I	Number of FREQ axis pixels	>= 1 (input data parameter; equal to global keyword NO_CHAN value)
CTYPE3	A	Name of FREQ axis.	'FREQ'
CDELT3	E	FREQ axis delta value.	Input data parameter (equal to global keyword CHAN_BW value).
CRPIX3	E	FREQ axis reference pixel.	1.0 (equal to global keyword REF_PIXL value)
CRVAL3	E	FREQ axis reference value.	Input data parameter (equal to global keyword REF_FREQ value).
MAXIS4	I	Number of IF axis pixels	1
CTYPE4	A	Name of IF axis.	'BAND'
CDELT4	E	IF axis delta value.	1.0
CRPIX4	E	IF axis reference pixel.	1.0
CRVAL4	E	IF axis reference value.	1.0
MAXIS5	I	Number of RA axis pixels	1
CTYPE5	A	Name of RA axis.	'RA'
CDELT5	E	RA axis delta value.	0.0
CRPIX5	E	RA axis reference pixel.	1.0
CRVAL5	E	RA axis reference value.	0.0
MAXIS6	I	Number of DEC axis pixels	1
CTYPE6	A	Name of DEC axis.	'DEC'
CDELT6	E	DEC axis delta value.	0.0
CRPIX6	E	DEC axis reference pixel.	1.0
CRVAL6	E	DEC axis reference value.	0.0
TMATX13	L	Column 13 ('FLUX') contains the UV data matrix	T
SORT	A	UV data table sort order	'TB' (UV data table rows are sorted by [time, baseline])
VISSCALE	E	UV visibility data scale factor	Input data parameter.

The number of bytes in each row of the UV_DATA table will be variable depending on the number of data frequency channels.

The VISSCALE keyword is specific to LWDA and is not part of the FITS-IDI base specification. It records the scaling factor which was applied to the UV data matrix values, both real and complex components. It represents a crude calibration of the raw data values into units of Janskys. If the UV data values contained in the UV_DATA table FLUX column are divided by the value, the original raw visibility measurement values can be recovered.

9.2 UV_DATA Table Data

LWDA FITS-IDI file UV_DATA tables contain 13 columns and a variable number of rows. Each row in the UV_DATA table corresponds to one UV measurement for one pair of instrument antennas for a given observation time. The column data is described below.

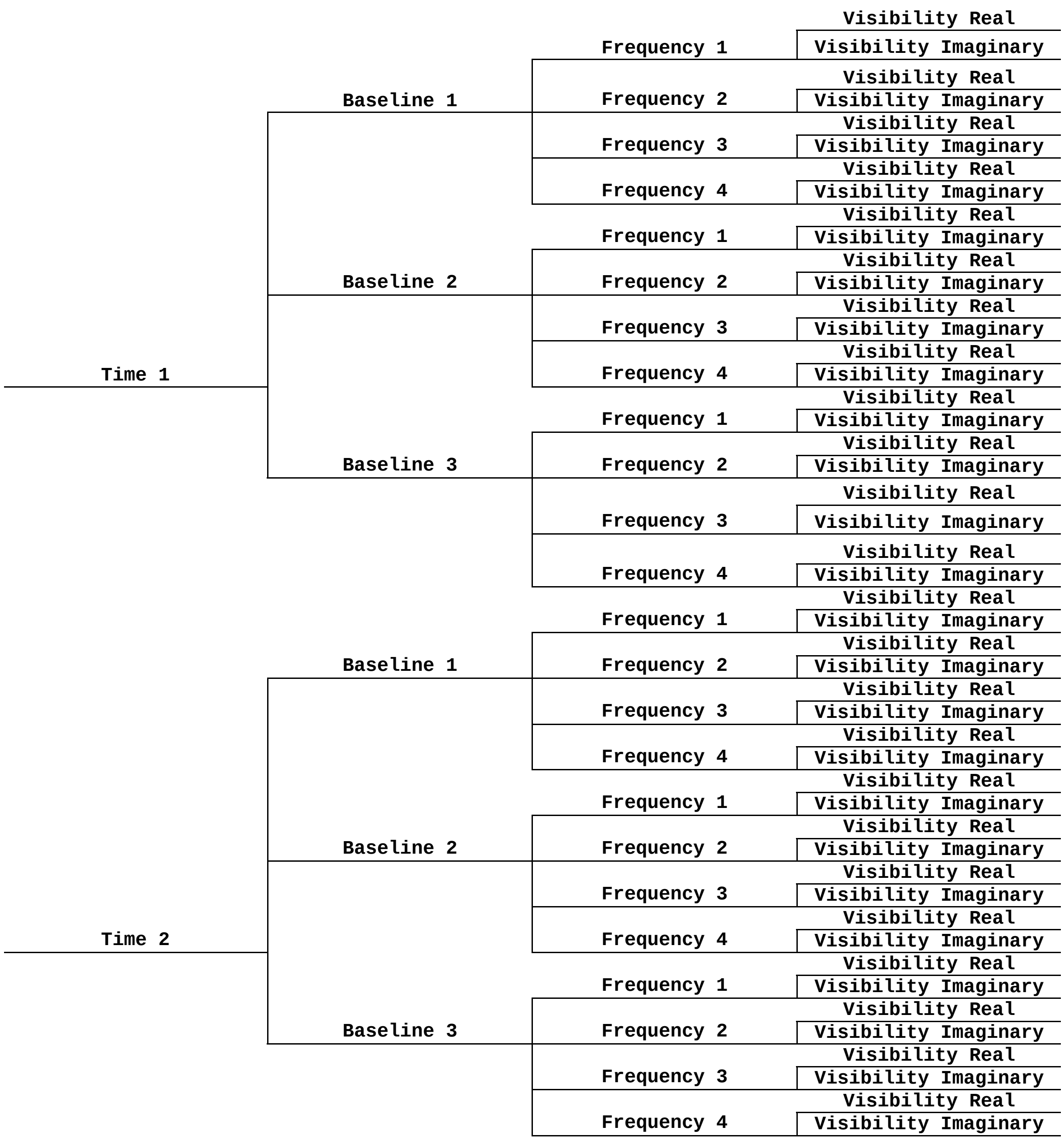
Table 17 - UV_DATA Table Columns

Column	Name	Format	Units	Description	Value
1	UU	1E	SECONDS	Baseline vector U coordinate	Input data parameter
2	VV	1E	SECONDS	Baseline vector V coordinate	Input data parameter
3	WW	1E	SECONDS	Baseline vector W coordinate	Input data parameter
4	DATE	1D	DAYS	UTC Julian day value for time 00:00:00 on the day of the observation	Input data parameter
5	TIME	1D	DAYS	Fraction of Julian day from UTC time 00:00:00 to UTC time of observation on day of observation.	Input data parameter.
6	BASELINE	1J		Antenna baseline pair ID.	Input data parameter.
7	FILTER	1J		VLBA filter ID	0
8	SOURCE	1J		Data source ID	1 - n
9	FREQID	1J		Data frequency setup ID.	1
10	INTTIM	1E	SECONDS	Data integration time.	Input data parameter.
11	WEIGHT	nE		Data weights (one element for each frequency channel)	1.0
12	GATEID	1J		VLBA gate ID.	0
13	FLUX	nE	JY	UV visibility data matrix.	LWDA UV data.

The WEIGHT column data arrays are of length NO_CHAN, with one weight value for each frequency channel in the UV_DATA. The FLUX column array is NO_CHAN * 2 elements in length. Each frequency channel in the UV data produces two visibility measurement values, one real and one imaginary. These two complex components are stored in the array inner dimension, while the frequency channels enumerate the outer dimension.

Appendix A - UV Data Matrix

The figure below is a schematic description of the UV_DATA table data matrix layout. This example has 4 frequency channels and three baseline pairs for two times.



Appendix B - LWDA Site Survey

This appendix contains the official LWDA array site survey data.

Table 18 - LWDA Array Antenna Locations

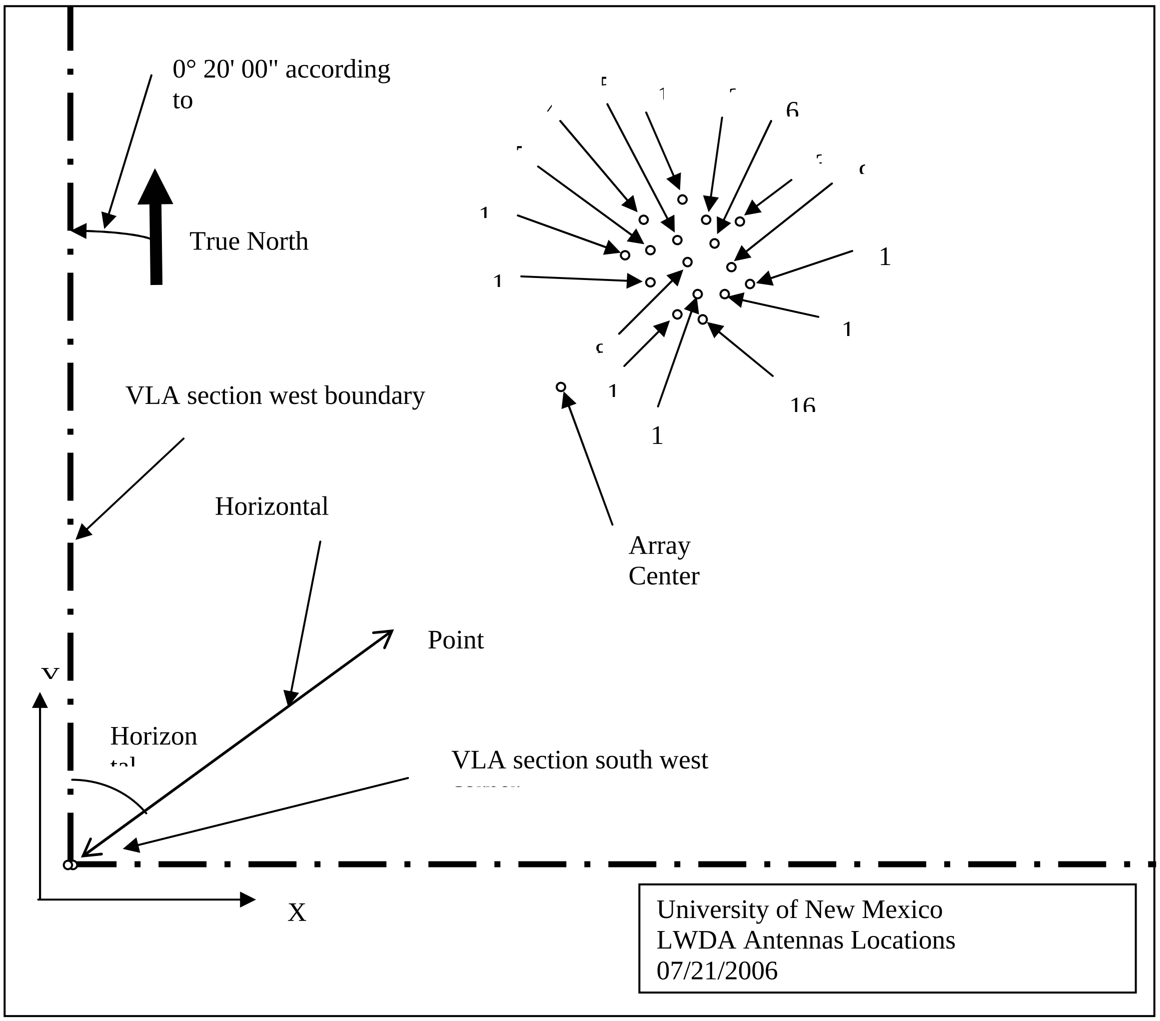
				Coordinates Origin at the VLA Section 1 South West Corner		Actual Coordinates With Origin at the Array Center.	
Antenna Number	Horizontal Distance (meters)	Horizontal Angle (degrees)	Z Coordinate (meters)	X Coordinate (meters)	Y Coordinate (meters)	X Coordinate (meters)	Y Coordinate (meters)
center	113.029	45.63917		80.810	79.027	0.000	0.000
1	148.728	42.45778	-2.716	100.398	109.728	19.588	30.701
2	149.104	44.48667	-2.622	104.484	106.373	23.674	27.346
3	152.691	46.00583	-2.633	109.848	106.057	29.038	27.030
4	142.178	41.56278	-2.532	94.327	106.382	13.517	27.355
5	143.374	44.08750	-2.438	99.753	102.982	18.943	23.955
6	147.378	45.91139	-2.419	105.856	102.541	25.046	23.514
7	139.203	43.26778	-2.320	95.411	101.362	14.601	22.335
8	141.981	45.58917	-2.280	101.423	99.358	20.613	20.331
9	146.737	47.74389	-2.226	108.607	98.673	27.797	19.646
10	135.781	42.26444	-2.281	91.320	100.485	10.510	21.458
11	135.331	44.75083	-2.159	95.276	96.109	14.466	17.082
12	139.455	47.58806	-2.131	102.962	94.056	22.152	15.029
13	142.858	48.74361	-2.110	107.396	94.205	26.586	15.178
14	147.058	49.37111	-2.106	111.609	95.758	30.799	16.731
15	134.711	47.66944	-1.976	99.588	90.715	18.778	11.688
16	137.57	49.07250	-1.995	103.940	90.123	23.130	11.096

Notes:
The VLA Section 1 west boundary is the "Y" axis and has bearing of 20' W of true north according to BLM records.
Horizontal distances (Column 2) were measured from the VLA section south west corner to each of the antennas.
Horizontal angles (Column 3) were measured clock wise from the west boundary line with vertex at the VLA Section 1 south west corner.
Z Coordinates are the elevation with origin at VLA Section 1 south west corner.
The array center elevation is unknown.
The antenna numbering order is as labeled at the field, which is different from the original specified.

The “Antenna Number” column value matches the NOSTA antenna ID in the ARRAY_GEOMETRY table, the ANTENNA_NO antenna ID in the ANTENNA table, and is used in composing the BASELINE values in the UV_DATA table. The antenna X, Y, and Z coordinate values relative to the VLA SW corner are used to calculate the antenna ECI vectors components recorded in the ARRAY_GEOMETRY STABXYZ column values.

The diagram below shows a plot of the LWDA array antenna layout.

Figure 2 - LWDA Antenna Layout



The reference point “VLA section south west” is taken as the “center” of the LWDA array. This point has ECI vector components S_X = -1602196.60 meters, S_Y = -5042313.47 meters, and S_Z = 3553971.51 meters. In geodetic coordinates, this position transforms to 252.372 degrees east longitude, to 34.069 degrees north latitude, and to 2127 meters of local elevation.

Appendix C – Baseline Coordinates

This appendix describes the transforms involved in converting the survey coordinates into coordinates required by the FITS-IDI format.

The starting point is the set of antenna position vectors defined in surveyor's coordinates relative to the VLA site SW corner. Each antenna has a relative position vector **R** = (R_E, R_N, R_H). Here, R_E is the relative position vector east-west component (survey *X* axis), R_N is the relative position vector north-south component (survey *Y* axis), and R_H is the relative position vector elevation component (survey *Z* axis). The **R** vectors provide the azimuthal (surveyor's) coordinates of the LWDA antennas.

The first step is to obtain the relative position vectors in the ECI reference frame. For each antenna relative position vector **R** = (R_E, R_N, R_H), the following transform is applied to get the ECI relative position vector **D** = (D_X, D_Y, D_Z):

$$\begin{vmatrix} D_X \\ D_Y \\ D_Z \end{vmatrix} = \begin{vmatrix} -\sin(\phi) & 0 & \cos(\phi) \\ 0 & 1 & 0 \\ \cos(\phi) & 0 & \sin(\phi) \end{vmatrix} * \begin{vmatrix} R_N \\ R_E \\ R_H \end{vmatrix}$$

Here, ϕ is the LWDA array geodetic latitude. Note that the D_Y is equal to the R_E component. The components D_X, D_Y, D_Z of the **D** vector for each antenna are stored in the ARRAY_GEOMETRY table STABXYX column.

For any two antennas, *A* and *B*, the ECI difference vector is **E** = $\mathbf{D_A} - \mathbf{D_B}$. This difference vector **E** is the baseline vector from antenna A to antenna B in ECI coordinates. The vector **E** has components **E** = (E_X, E_Y, E_Z).

The last step is to obtain the coordinates of each baseline vector in the *UVW* coordinate system. The following transform converts the vector **E** = (E_X, E_Y, E_Z) into the baseline vector **B** = (B_U, B_V, B_W) in the *UVW* coordinate system:

$$\begin{vmatrix} B_U \\ B_V \\ B_W \end{vmatrix} = \begin{vmatrix} \sin(\eta) & \cos(\eta) & 0 \\ -\sin(\delta) * \cos(\eta) & \sin(\delta) * \sin(\eta) & \cos(\delta) \\ \cos(\delta) * \cos(\eta) & -\cos(\delta) * \sin(\eta) & \sin(\delta) \end{vmatrix} * \begin{vmatrix} E_X \\ E_Y \\ E_Z \end{vmatrix}$$

This is dependent on the phase center pointing location in equatorial coordinates for the LWDA array at the time of the observation. Here, δ is the declination angle of the phase center pointing direction, and η is the hour angle of the phase center pointing direction for the LWDA site. When FITS-IDI files record LWDA all-sky wide-field imaging data, the equatorial coordinates are given by the time of the observation and by the assumption that the phase center of the array is pointed at the local zenith of the LWDA site. In this case, $\eta = 0$, and $\delta = \phi$, the latitude of the LWDA site from above. This simplifies the matrix transform to:

$$\begin{vmatrix} B_U \\ B_V \\ B_W \end{vmatrix} = \begin{vmatrix} 0 & 1 & 0 \\ -\sin(\phi) & 0 & \cos(\phi) \\ \cos(\phi) & 0 & \sin(\phi) \end{vmatrix} * \begin{vmatrix} E_X \\ E_Y \\ E_Z \end{vmatrix}$$

Note that this makes the B_U component equal to the E_Y coordinate.

As a final step, the FITS-IDI format requires the *UVW* coordinates of the baseline vector **B** = (B_U, B_V, B_W) to be scaled by dividing by the velocity of light c = 2.99792458 x 10^8 meters / second. This makes the units of the baseline vector *UVW* coordinates seconds. These scaled values of (B_U / c), (B_V / c), and (B_W / c) are stored in the UU, VV, and WW columns of the UV_DATA table for each pair of antennas contributing to the visibility data.